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SYSTEM HAZARD ANALYSIS OF

TACOM'S

RIDE MOTION SIMULATOR

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This report presents a complete safety hazard analysis report for the Ride Motion Simulator. The report presents a general overview of system hazards as well as a detailed breakdown of all hazards, their severity and probability of occurring, and an explanation of the safety backups.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

This report provides a System Hazard Analysis (SHA) of the Ride Motion Simulator (RMS) located at the United States Army Tank-Automotive Command (TACOM) in Warren, Michigan. It also provides the U.S. Army Test-Evaluation Command with component descriptions and hazard analyses of the RMS.

The Ride Motion Simulator was designed to include provisions for safeguarding personnel. Safety devices have been located on the equipment where necessary and are described in TACOM Technical Report No. 13464, "USER's MANUAL FOR THE RIDE MOTION SIMULATOR."

This System Hazard Analysis (SHA) is submitted concurrently with a Safety Analysis Report (SAR) in an effort to obtain a safety release for the Ride Motion Simulator.

The scope of this System Hazard Analysis is the systematic assessment of real and potential hazards associated with the sybsystems of the Ride Motion Simulator. This SHA was conducted on the available system concept data in an attempt to identify hazards and then direct design efforts toward the elimination or control of the identified hazards.

2.0 OBJECTIVES

The primary goal is to obtain a Safety Release from the U.S. Army Test and Evaluation command. This report is issued in conjunction with TACOM Technical Report No. 13470, "SAFETY ASSESSMENT OF TACOM's RIDE MOTION SIMULATOR" and TACOM Technical Report No. 13464, "USER's MANUAL FOR THE RIDE MOTION SIMULATOR" in an attempt to satisfy MIL-STD-882B.

3.0 CONCLUSIONS

All known safety hazards have been evaluated throughout the analysis of the Ride Motion Simulator. The system is considered safe to operate as long as the procedures stated in the "USER's MANUAL FOR THE RIDE MOTION SIMULATOR" are followed.

The safety devices and procedures for the Ride Motion Simulator will reduce the probability of injury to occupant or damage to equipment to the levels dictated in MIL-STD-882B.

4.0 RECOMMENDATIONS

Upon issuance of a safety release for the Ride Motion Simulator, it is suggested that the Safety Office at TACOM be given power to approve various test setups and issue safety releases for them.

5.0 DISCUSSION

5.1 System Description

The Ride Motion Simulator is fundamentally a platform mounted in a framework such that four motions (four degrees of freedom) can be imparted to it simultaneously: linear motion along the vertical axis; rotational motion about the vertical axis (yaw); rotational motion about the transverse axis (pitch); and rotational motion about the longitudinal axis (roll). The motions are generally oscillatory in nature and comparable to the motions experienced in the crew compartment of a wheeled or tracked vehicle under mild to severe off-road operating conditions. The platform is large enough to allow simulation of a crew station or to simply evaluate a seating configuration. Investigations can be conducted on human tolerance to vibrations in general or on task performance in a vibrational environment.

In the current configuration the input signals are generated from computer data files created on a CRAY-2 supercomputer using computer simulation of an army vehicle operating over specific terrain profile courses (APG, Ft. Knox, etc.). These files are then modified and used to drive the Ride Motion Simulator using a micro-VAX II computer. With this configuration, a wide range of vehicles, courses, and seatings (gunners, commanders, drivers, etc.) can easily be simulated and recreated on the Ride Motion Simulator.

5.2 Major Subsystems and Components

The RMS is described under the following equipment categories: (Figures 5-1 through 5-9 are photographs of the RMS and associated equipment).

- Computer Automated Measurement and Control (CAMAC) Computer System.
- Electronic conditioning modules.
- Pneumatic control panel.
- Motion system.
- Hydraulic control panel.

5.3 Analysis Summary

The analysis results presented on the following pages address the hazard potential to the Ride Motion Simulator should there be a failure in any of the sybsystems. The hazards, due to a structural failure, were analyzed by Structural/Kinematics of Troy, MI, under contract #DAAE07-84-R047 and are presented in TACOM Technical Report #13150, "STRUCTURAL ANALYSIS OF TACOM RIDE SIMULATOR."

5.4 Assignment of Risk Assessment Codes

The accompanying analysis sheets contain hazard severity levels, hazard probability levels and Risk Assessment Codes (RAC). The hazard probability levels and RAC are from AR 385-10 Interim Change

No. I01. The hazard severity levels are from MIL-STD-882B, so that system damage and personnel injury can be included in the definition and reflected in the hazard assessment.

HAZARD SEVERITY

a. Category I - Catastrophic. May cause death or system loss.

b. Category II - Critical. May cause severe injury, severe occupational illness, or major system damage.

c. Category III - Marginal. May cause minor injury, minor occupational illness, or minor system damage.

d. Category IV - Negligible. Will not result in injury, occupational illness, or system damage.

HAZARD PROBABILITY

A - Likely to occur immediately

B - Probably will occur in time

C - Possible to occur in time

D - Unlikely to occur

RISK ASSESSMENT CODES

1 - Critical

2 - Serious

3 - Moderate

4 - Minor

5 - Negligible

5.5 Safety Analysis of the Ride Motion Simulator

The hazard evaluation of the RMS is made with a higher degree of confidence than would be expected for an entirely new system. The basic hardware, as related in the User's Manual for the Ride Motion Simulator, has been in existence since the late 50's and has been in its present location in Bldg. 215 since 1972. During it's nearly 30 year existence, it has been used in various ride- and task-oriented studies involving human participants. In the entire history of the simulator, no injuries have been documented. Thus, based on historical data, the RMS could be considered rather nonhazardous.

The technological upgrading that has taken place recently is oriented at meeting the more stringent criteria that have developed in a highly safety-conscious society. Additionally, the introduction of more sophisticated input techniques have also led to new failure paths not found in earlier iterations of the simulator.

The hazard assessment is divided into two parts as follows:

- A general overview of basic hazards.

- An analysis of each possible hazard, failure probability and backup systems.

5.5.1 General. The simulator is located in a large, air-conditioned building built in 1972, which was designed as a laboratory for the investigation of tracked and wheeled vehicle suspensions. Facilities exist for testing components and complete systems up to the size of a main battle tank turret or heavy truck (40 tons). The building is equipped with a high-capacity electrical system (480, 240 & 120 VAC), a central hydraulic system and a central compressed air system. The simulator is located in a medium-sized room shared with CRAY research personnel. The room has fluorescent lighting and an acoustic ceiling. Both the sound and lighting levels were found to be meeting O.S.H.A. and GSA standards (see Appendix A for tests). Nothing in the room normally generates toxic fumes.

5.5.2 Basic hazards.

5.5.2.1 Simulator installation. The simulator frame is anchored in the floor of a rectangular concrete lined pit, which is set against one wall of the room. The pit is approximately 10 ft sq. and 8½ ft. deep. The top of the pit is covered by heavy, metal "egg crate" style grates, except for the area through which the simulator frame projects. There is access to the simulator on all sides. The grate is a hazard to individuals wearing high-heeled shoes, i.e., shoes with small heel ground contact area. All the hydraulic components used to power the simulator are located in the pit.

5.5.2.2 Simulator structural integrity. The physical failure of the simulator is a possibility. The probability of its occurrence was established by an independent consultant, Charles S. Stanton, Structural/Kinematics of Troy, Michigan. The analysis included brittle lacquer techniques followed by strain gauging in those areas identified by the brittle lacquer as highly stressed. The conclusion drawn by the consultant firm was the probability of structural failure (in the hour of operation following the accrued test hours) was less than 10^{-7}.

5.5.2.3 Simulator operating hardware. The two motors which power the system are drip-proof, fan-cooled motors that operate well within their respective ratings. The hydraulic components, hoses, and tubing are all industrial quality, rated for operating pressures

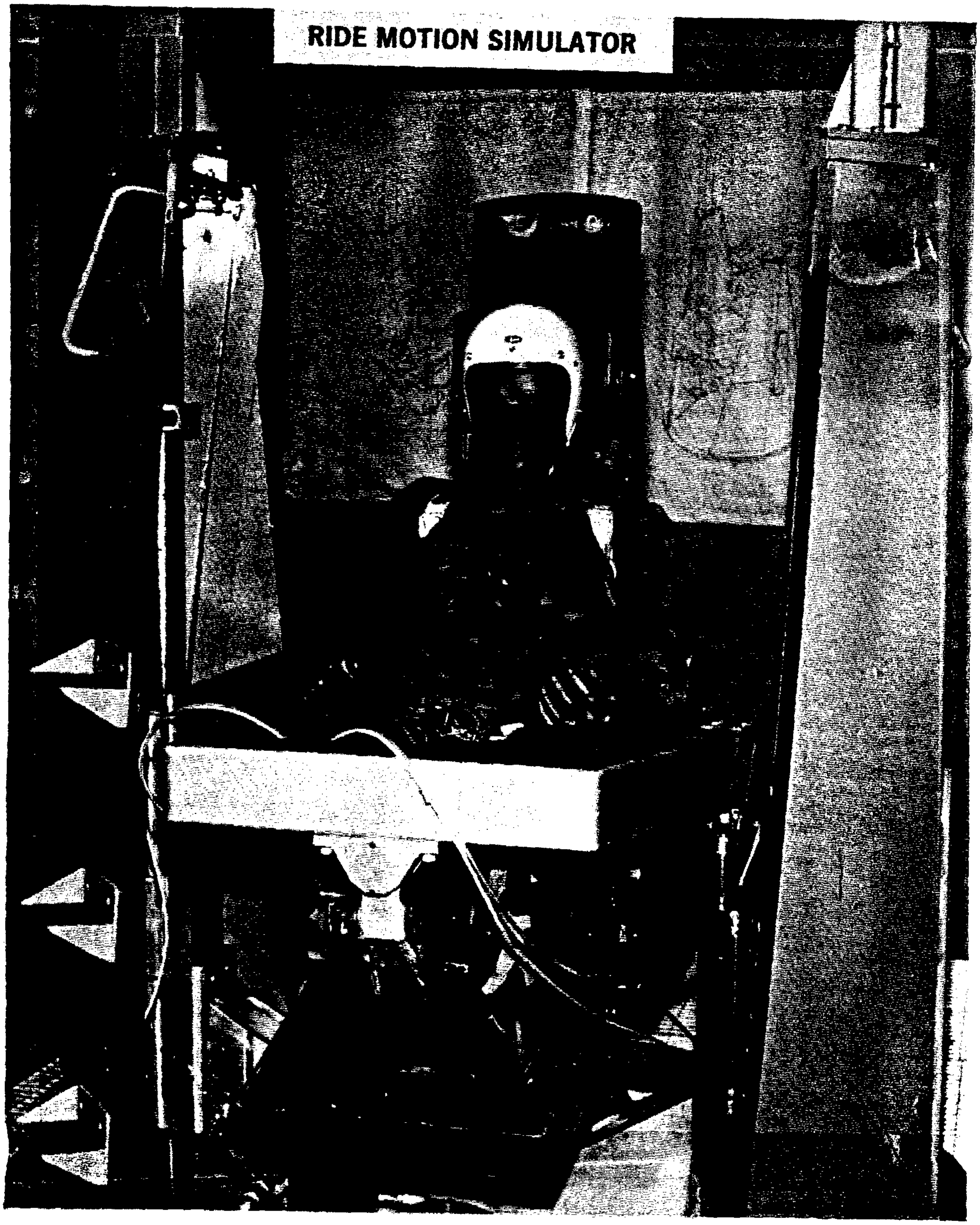


Figure 5-1. Ride Motion Simulator

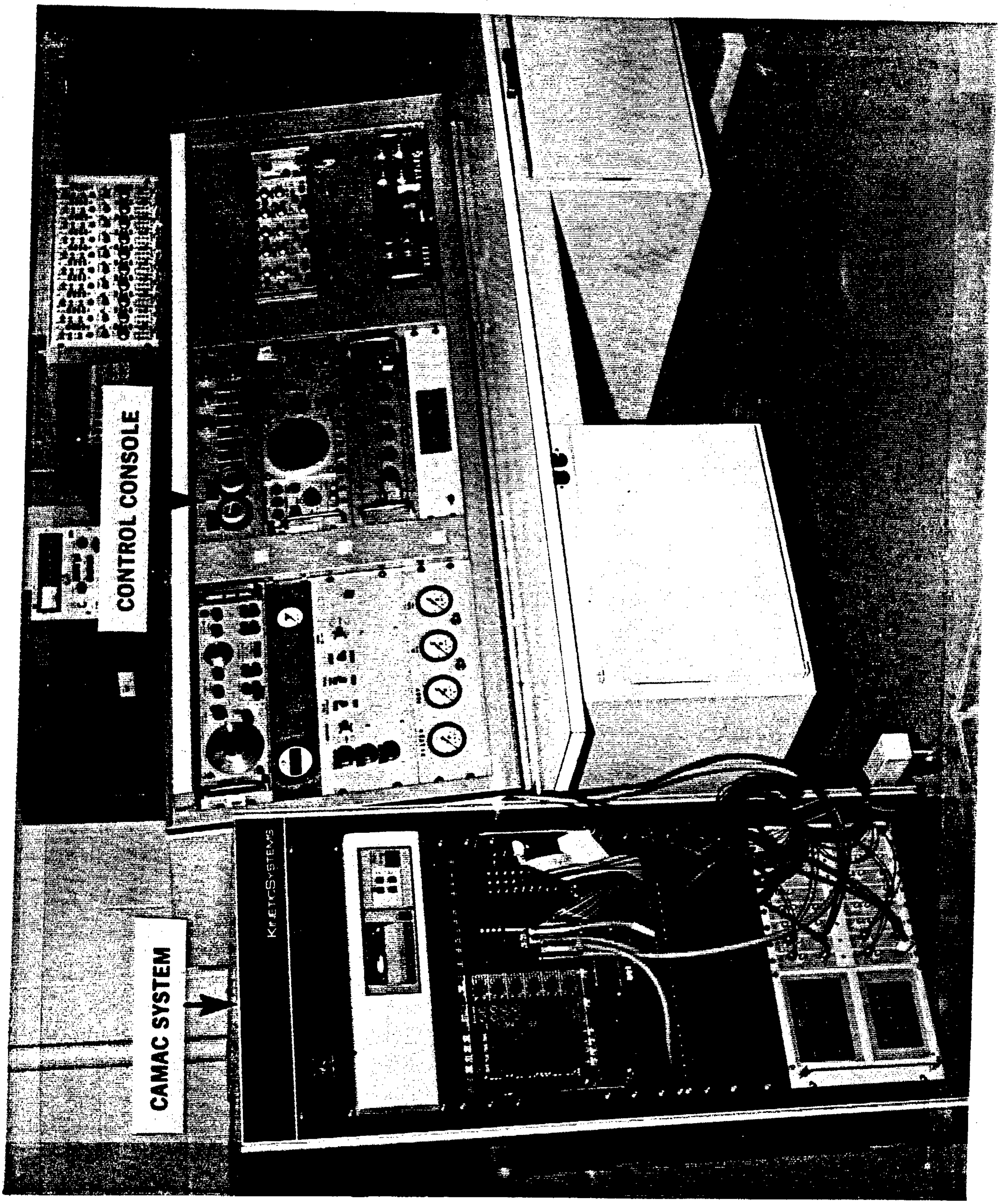


Figure 5-2. CAMAC System and Control Console

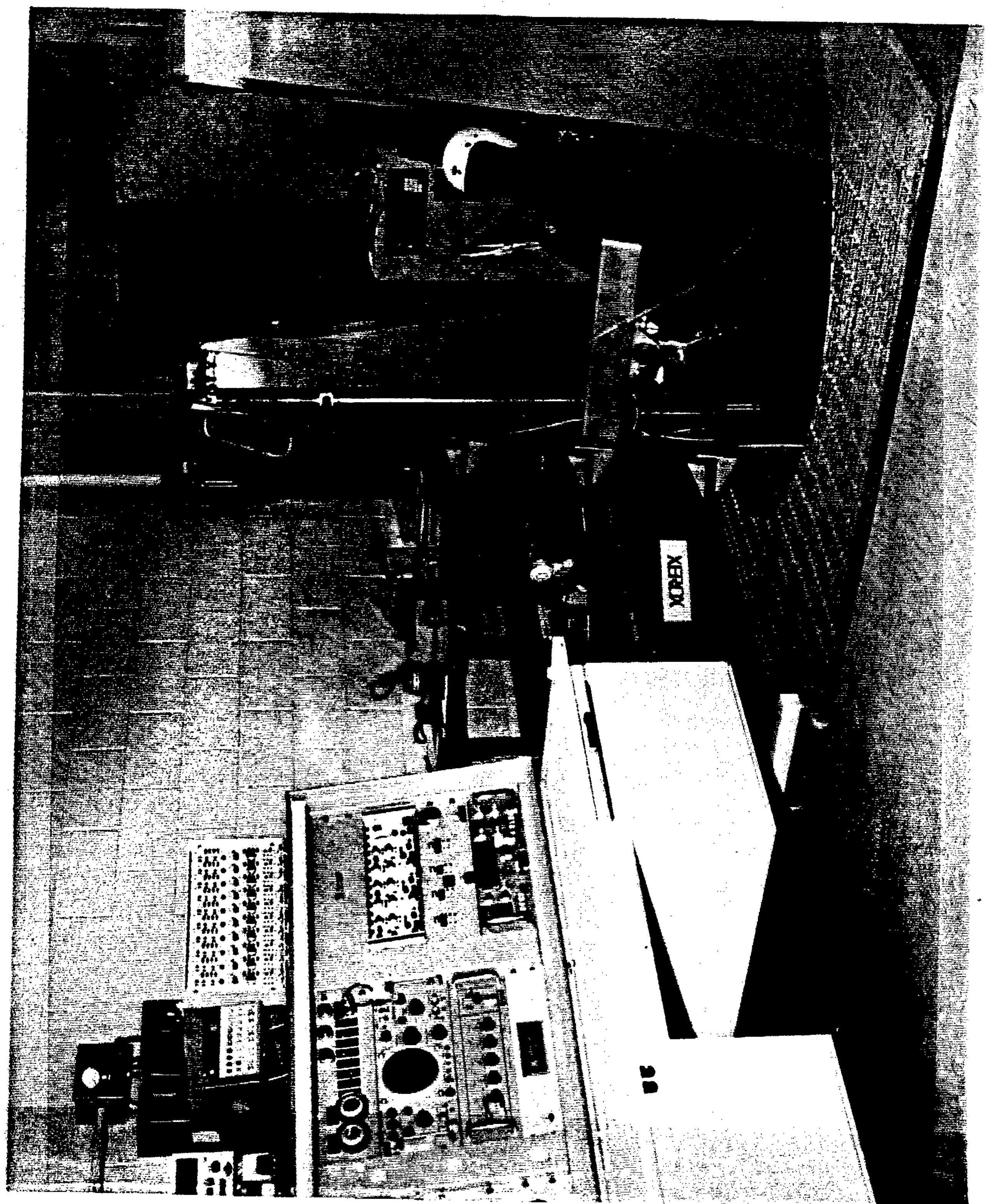


Figure 5-3. RMS Bay Room

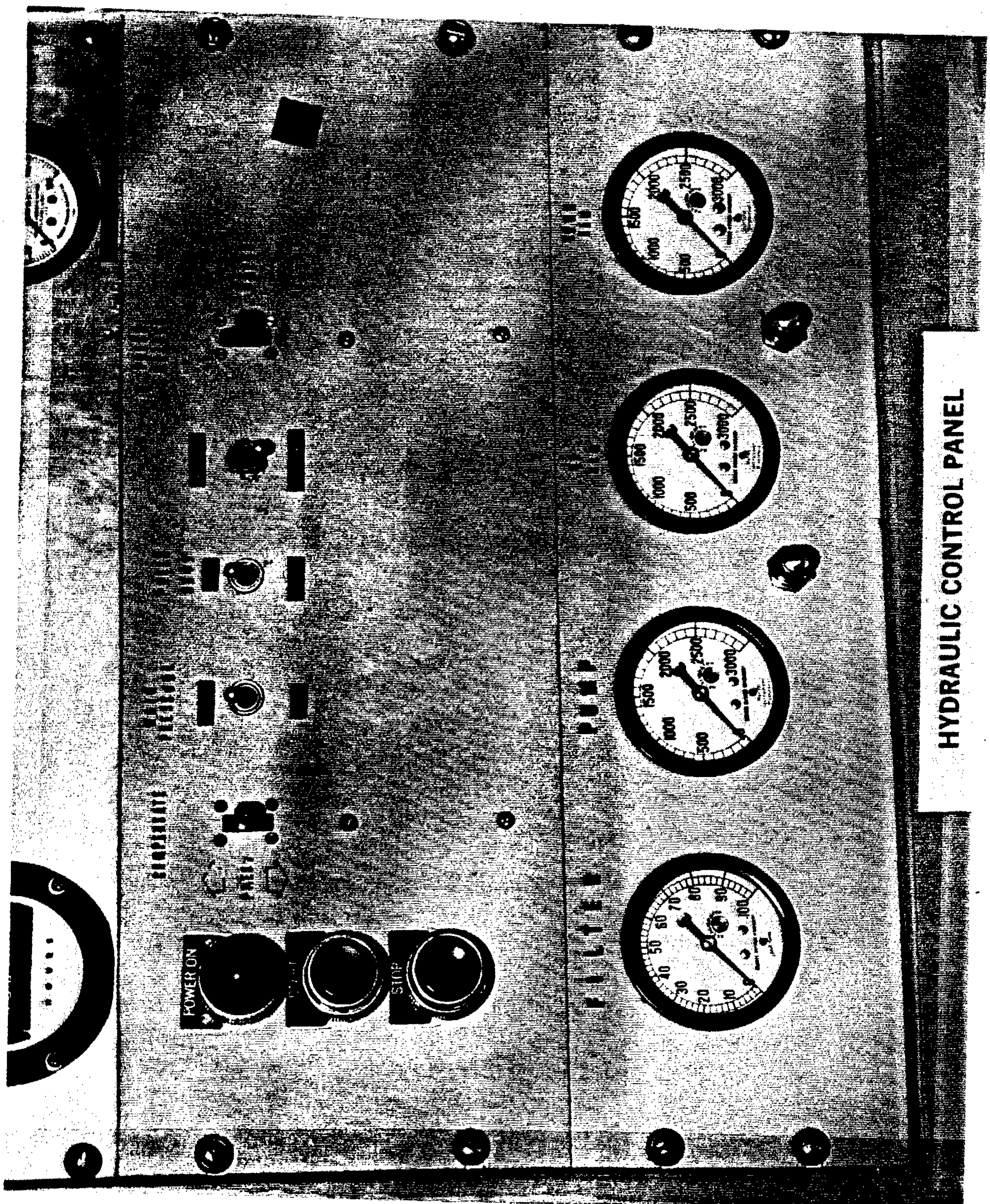


Figure 5-5. Hydraulic Control Panel

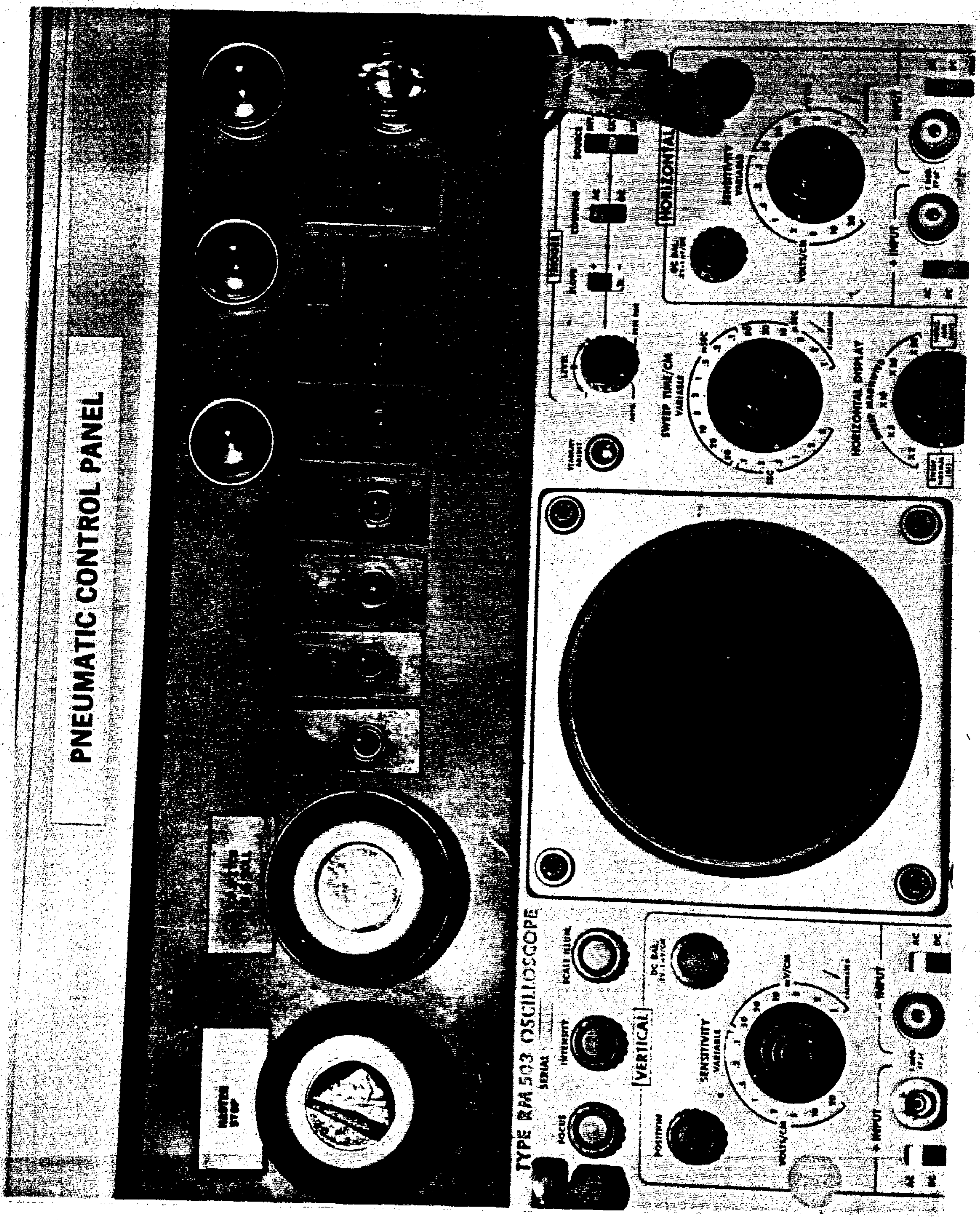


Figure 5-6. Pneumatic Control Panel

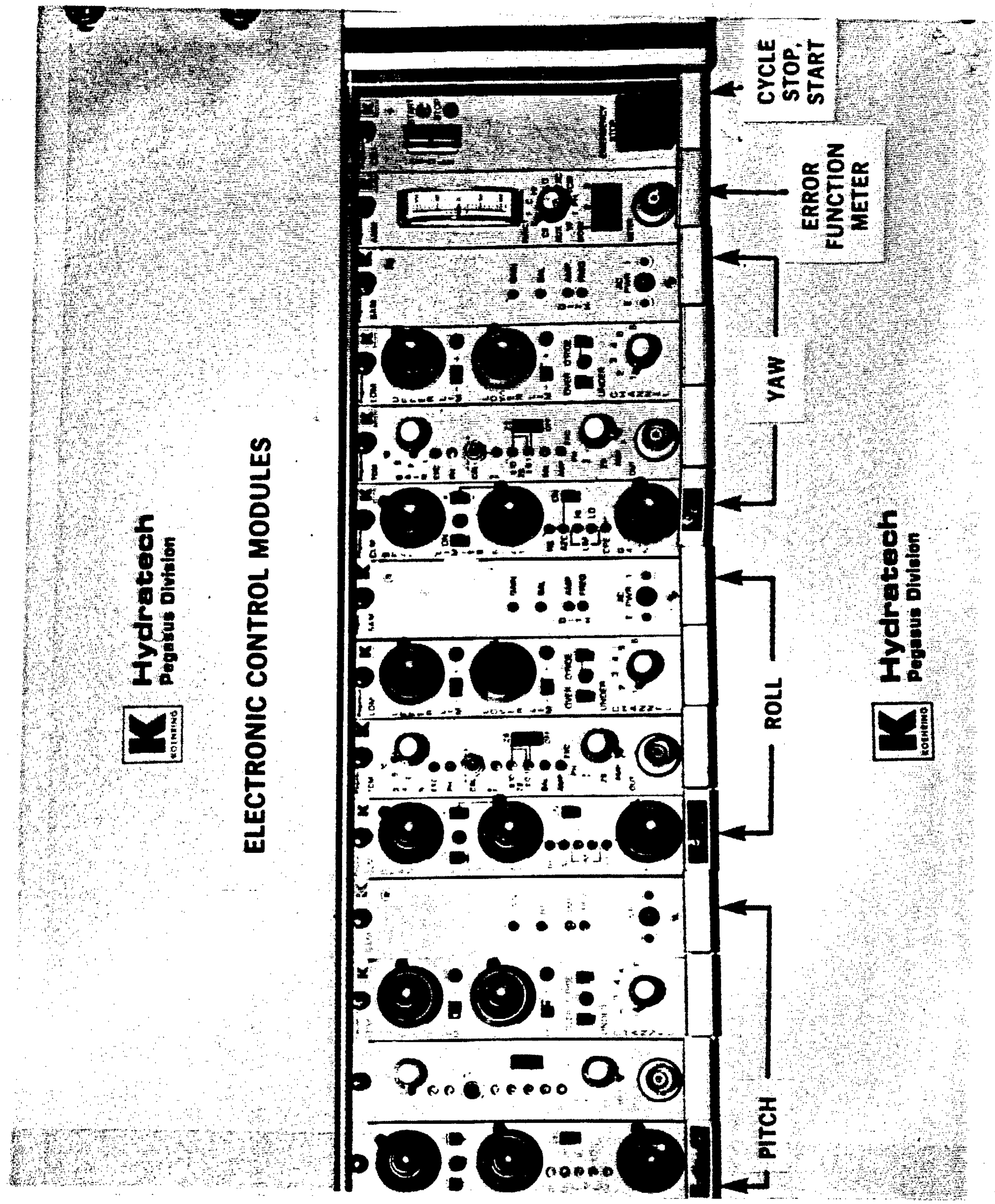


Figure 5-7. Electronic Control Modules (Roll, Pitch, Yaw)

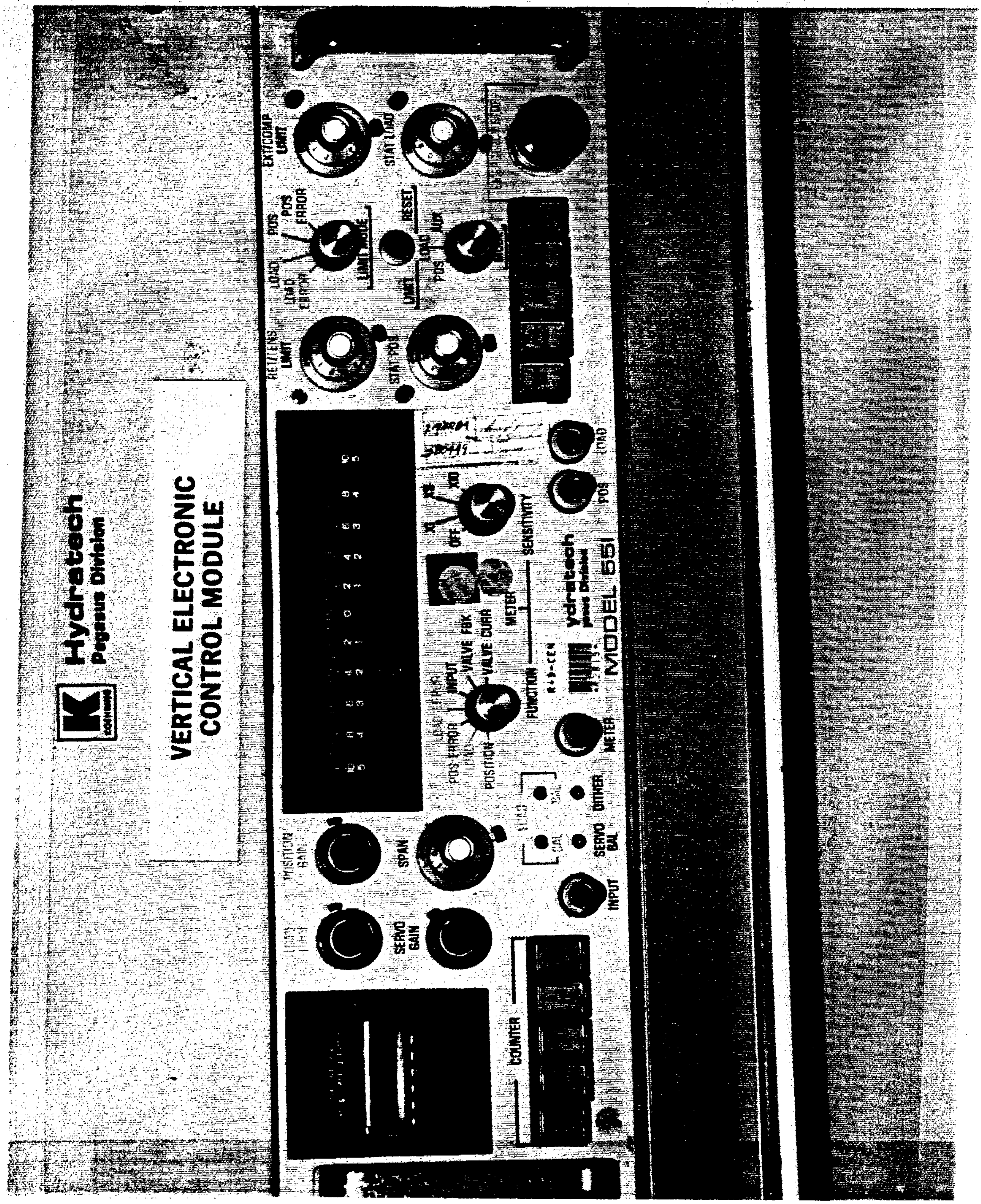


Figure 5-8. Vertical Electronic Control Panel

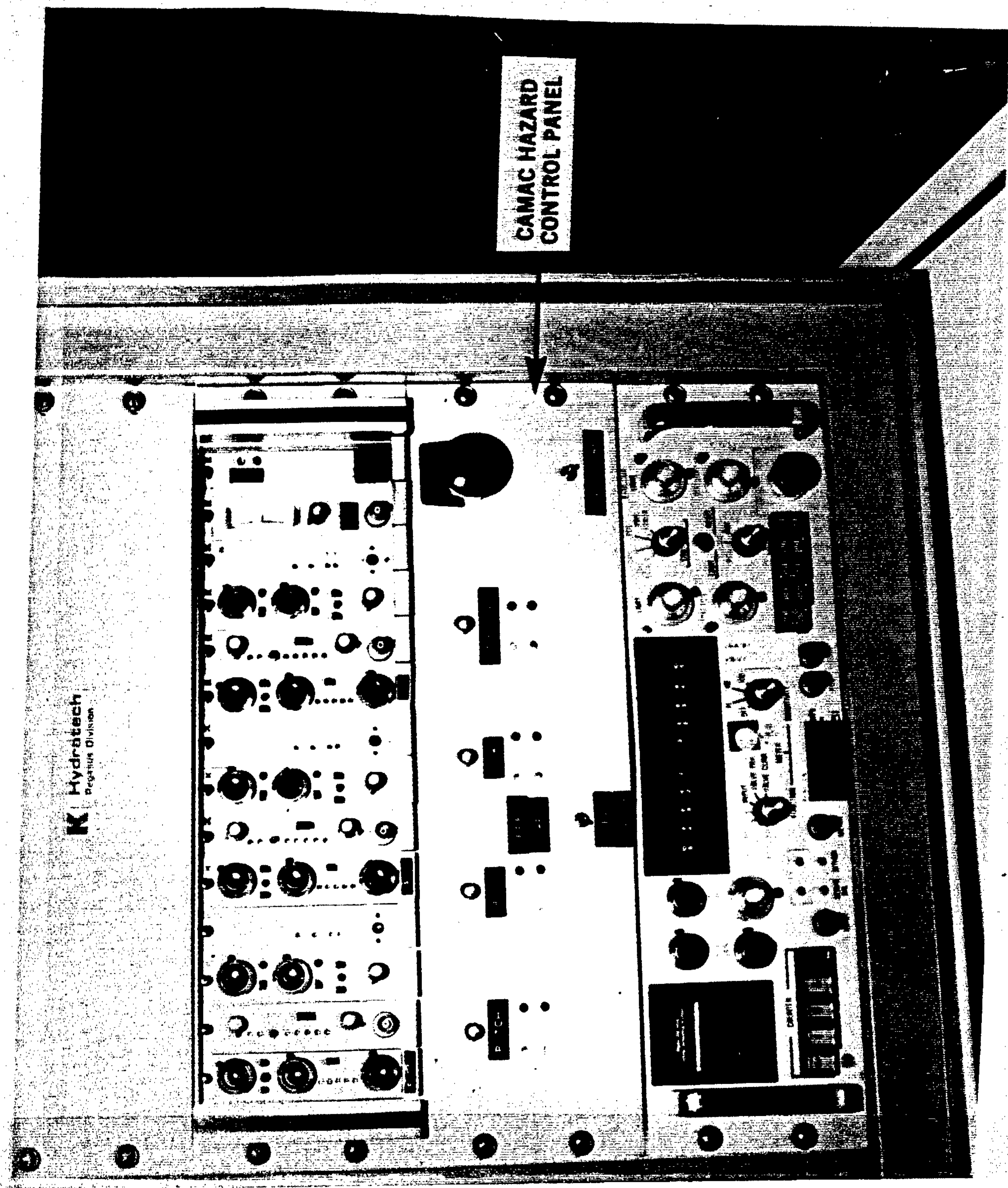


Figure 5-9. CAMAC Hazard Control Panel

up to 3000 psi. Catastrophic failure of hoses, hose ends, tubing, tube fittings or valves is very remote. Further, catastrophic failures (such as hose tubing breaks) are usually preceded by small scale leaking or mechanical deformation for a substantial length of time. To guard against the above, visual inspections will be conducted prior to the initiation of a test program and at periodic intervals during testing (see the User's Manual for the Ride Motion Simulator). Leaking components will be repaired or replaced, as necessary. The reservoir (200 gallons) is baffled and vented to the atmosphere. Servo valve sticking, as a result of dirt in the oil, is also a possibility. Two filter banks of four filters each are provided in the system, one specifically to protect the vertical axis motion. The condition of the filters is monitored by the pressure drop across the filters. The filter elements will be replaced as required.

Because of the remote probability of failure of the hydraulic components and reservoir, there is no shielding surrounding the hydraulic equipment.

5.5.2.4 Hydraulic system failures. Power loss to the main hydraulic pump and coolant pump is a possibility but is not a hazard. Essentially, loss of power to the main pump would cause the simulator to coast to a stop. Oil delivery from the pump would stop almost instantly, but the system would continue to receive oil from the accumulators for a short period of time at ever decreasing pressure. Ultimately, the residual pressure would be equal to pre-charge pressure, but the flow rate would be "zero." Power loss to the coolant pump would result in unchecked heat build-up in the system working fluid. However, the heat absorbing capacity of the reservoir, approx. 200 gallons of oil, is very large and the power utilization of the system so low that heat build up would occur very slowly and would be readily observable on the system temperature gauge long before it became dangerous. The reservoir is baffled and vented to the room atmosphere. Normal operating temperature of the system ranges from room temperature to 120°F. The oil-to-water coolant system, used to maintain or reduce the temperature of the working fluid, is activated manually when the maximum temperature is reached. Loss of coolant water flow or other coolant system breakdown results in the same slow increase in working fluid temperature as described above, thus giving adequate warning for shut downs. Both electrical and oil fires are possible but are considered remote.

5.5.2.5 Electrical system failure. All electrically operated equipment in the pit are of industrial quality and, thus, benefit from the regulations governing the safety of such equipment. The equipment functions normally even when wet with oil. The electric motors are protected from internal contamination from anything except sprays directed from underneath. Finally, the low-operating temperature of the working fluid and its low volatility lessens the fire hazard.

5.5.2.6 Control console fire. Control console fire is a

possibility; however, it is minimized by using only industrial-rated devices operating within their rated capacity. Further, the installation of console equipment is carried out in accordance with best practice. In the event a fire should occur in the console or the pit area, manually operated fire extinguishers rated for Class A and Class B & C fires are within 10 feet of the console.

5.5.2.7 Pneumatic system failures. The pneumatic system is an independent network of automatic and manual safety shutdown devices which provides backup to electrical shutdown circuits. But it, too, has the possibility of failing. Loss of air pressure, brought on by a major leak or a stoppage of the supply, triggers a system shutdown and thus is considered a safe event. The system is comprised of several elements among which are travel-limit switches for vertical motion on the simulator. Should the simulator, for any reason, exceed the excursion limits defined by the switches, the tripping of a switch will initiate a system shutdown. If a limit switch is tripped but fails to initiate a system shutdown, electrical backup systems are in place which are designed to perform the same function by sensing other indicators of motion. However, an over-travel situation does not necessarily define an occupant injury. Three manual switches are in the system intended for occupant use. Two are of the "press-to-activate" type, and the third is a "release-to-activate" or "dead-man's" switch. The switches can be used in an either-or arrangement, depending on the type of test being performed. Activation of the switches means that the occupant is, or perceives to be in a threatening situation and, thus, their functioning correctly is important. In the event they are activated but fail to shut down the system, the system operator must recognize the failure of the switches to work and initiate a shutdown. Malfunctions of switches, due to contaminated air, are minimized by passing the air supply through a filter and water separator before entering the system. The occurrence of breaks are minimized by scheduled inspections of the systems.

5.5.2.8 Electronic system failures. The electronic system could be a problem if bad data or noise are input to the servos. However, electronic equipment is highly reliable under normal operating conditions, so failure is remote. Following is a breakdown of the electronic system.

° CAMAC system. There are essentially two things which could cause a problem:

- a failure of the output circuitry, or
- a bad data file ("bad" meaning the data would cause unacceptable G forces or exceed the travel limits).

The main cause of failure to circuitry is excessively high temperatures. The room is air-conditioned and the CAMAC system has an internal cooling fan. Also, before a test is run, the output data going to the electronic conditioning modules is monitored on a strip chart recorder. This will reduce the chance of a failure occurring during a test to extremely

improbable.

All data files will be checked by the CAMAC computer programmer for continuity before they are output. This will safeguard against large G forces by not allowing any large instant position change.

° The electronic conditioning modules. These modules are specifically designed for passing electric signals to hydraulic systems. These modules are of industrial quality and thus benefit from the regulations governing the safety of such equipment.

° Position feedback instruments. All actuators on the RMS have their positions electrically measured. Pitch and vertical use a LVDT (Linear Variable Differential Transducer) while roll and yaw use electrical potentiometers. The LVDT is a highly reliable instrument and should never fail. The potentiometers will be checked according to a routine maintenance schedule and replaced as necessary. This will lower the probability of failure occurring during a test.

5.5.2.9 System response. The low dynamic bandwidths of the Ride Motion simulator provide a safety feature in itself. The bandwidths of the four degrees of motion are:

VERTICAL	5.5 Hz
ROLL	8.2 Hz
PITCH	9.0 Hz
YAW	1.0 Hz

Bode plots from closed-loop test are included in Appendix B. The low bandwidths will help to prevent sudden spikes from occurring. Even if a spike were input to the system, the simulator could not reproduce it, thus preventing injury and damage.

5.5.2.10 Seating configurations. The Ride Motion Simulator has the capability to accomodate a wide variety of seating configurations. All seats used on the RMS will be equipped with seat belts and/or a shoulder harness. The simulation used to recreate seat motion takes into account the spring mass system of the vehicle.

5.5.3 System hazard analysis. The following pages outline specific failures, hazard probabilities and severity and provide a flow-chart showing related backup systems.

SYSTEM HAZARD ANALYSIS

SUBJECT HAZARD OR UNDESIRED EVENT	PROGRAM PHASE	CAUSE	EFFECT	HAZARD SEVERITY	HAZARD PROBABILITY	RAC	COMMENTS CORRECTIVE ACTION/MINIMIZING PROVISIONS
Loss of pneumatic pressure	Startup and operation	Break in hose, failure of compressor	Hydraulic stops will activate, system will stop	IV	C	5	Loss of air pressure or malfunction of the low pressure shut-down mode does not by itself imply an occupant injury situation. The RMS motions are limited by an electronic position sensor and a signal monitoring circuit. The loss of air-pressure will trigger the hydraulic stops and bring the RMS to an immediate stop.
Loss of "Press to Activate" Pneumatic Switch	Operation	Failure in switching mechanism	Renders this particular means of safety shutdown ineffective	IV	C	5	Loss of the "Press to Activate" pneumatic shutdown switch in itself presents no hazard to the occupant. These switches are used by the test subject to stop the test upon perception of danger. If the perception of danger is accurate, the operator would take independent action to shut-down the system in the event he observes that activation of either switch does not shut-down the system or he notices a hazard.
Loss of "Release to Activate" (DEAD-MAN) Pneumatic Switch	Operation	Failure in switching mechanism	Renders this particular means of safety shutdown ineffective	IV	C	5	Loss of the "Release to Activate" pneumatic shutdown switch in itself presents no hazard to the occupant. This switch is used by the test subject to stop the test upon perception of danger or in the event of actual injury. If the perception of danger is accurate or an injury occurs, the operator would take independent action to shut-down the system in the event he observes that activation of the switch does not shut-down the system.
Loss of Pneumatic Vertical Travel Limit Switch	Startup and Operation	Failure in switching mechanism	Loss of these switches (upper and lower) prevent the pneumatic system from aborting the test in case of vertical over-travel.	IV	C	5	Automatic backup to these switches is provided by electronic limiting devices which notify the controlling computer of over-travel. The computer then ramps down the input signal and within 5-10 seconds aborts the test. Manual backups are provided for the test subject ("Press to Activate" or "Release to Activate" pneumatic switches) and the operator. Loss of these switches by itself does not induce a hazard situation.
Loss of Pneumatic "Red" Master Stop Button	Operation	Failure in button operation	Prevents one button stopping of all motion by the operator	IV	C	5	Backup due to the malfunction of the "Red" master stop button is provided to both the RMS operator and the seat occupant. The operator can cut off hydraulic power by toggling the main pressure switch to "OFF" or he can press the CAMAC emergency shutdown switch to freeze the input signals at their current level, thus stopping motion. The occupant can either let go of the "Dead-mans" switch or press the shutdown switch (depending which switch is enabled). Loss of the "Red" master stop pneumatic button in itself presents no hazard to the occupant.
Loss of Hydraulic Pressure	Startup, operation and shutdown	Loss of pump power, blockage in lines, clogged hydraulic filters, burst in hose or failure of release valve	Power to the RMS will end	IV	C	4	Loss of system pressure due to any listed reason implies a decrease in flow volume and hence the actuators would slow down and eventually stop completely as the oil supply from the accumulators is also depleted.
Large scale oil leakage	Startup, operation and shutdown	Burst in hose or rupture in manifold	Power to the RMS will end, release of hydraulic oil into room	II	C	4	The exact location of the failure and the equipment wetted by the escaping oil determines the severity of the hazard. The hazard to personnel varies with the amount and velocity of the oil delivered and point of impact. Burn hazard is non-existent based on the maximum oil temperature being limited to 120°F. Immediate control of the hazard depends on system shutdown by the operator. A good preventative maintenance program and periodic inspection of equipment keeps the probability of occurrence remote. Secondary effects of large oil leaks include the inability of the hydraulic system to drive one or more motion actuators in accordance with input signals.
Small scale oil leakage	Startup, operation and shutdown	Leak in hose, poor seals, etc.	Dripping or fine spray of hydraulic oil	IV	B	4	Leaks composed of dripping and fine sprays are not an immediate hazard, however, routine shutdown procedures must proceed so that repairs can be made. Small scale leaks would have no impact on hydraulic system performance. The presence of wet oil films pose minor threat of fire if exposed to open flames or sparks due to the high flashpoint of the oil (395°F).

SUBJECT HAZARD OR UNDESIRED EVENT	PROGRAM PHASE	CAUSE	EFFECT	HAZARD SEVERITY	HAZARD PROBABILITY	RAC	COMMENTS CORRECTIVE ACTION/MINIMIZING PROVISIONS
Loss of Vertical Servo-valve	Startup, operation and shutdown	Sticking of servo-valves	High input pressure released to actuators causing sudden movement to extreme positions	II	C	3	Failure implies the vertical actuator travels to an extreme position. In this degree of freedom, the pneumatic vertical travel switches will prevent damage from occurring. The RMS operator can also stop the test by pressing the "Red" master stop button, or the test subject can activate the manual pneumatic switch. Following the maintenance schedule and the pre-test checklist will reduce the chances of the servo actually failing to negligible.
Loss of Roll, Pitch or Yaw Servo-Valves	Startup, operation and shutdown	Sticking of servo-valves	High input pressure released to actuators causing sudden movement to extreme positions	III	C	4	Failure implies the roll, pitch, or yaw actuators will travel to an extreme position. In these degrees of freedom, the RMS operator can stop the test by pressing the "Red" master stop button, or the test subject can activate the manual pneumatic switch. Following the maintenance schedule and the pre-test checklist will reduce the chances of the servo actually failing to negligible. Run-away motion in roll, pitch, or yaw will not pose the physical threat to a test subject that vertical will.
Failure of UPS system	Startup, operation and shutdown	Electrical failure in UPS	Fluctuations in electrical supply power to the RMS	II	D	5	The UPS (Uninterruptible Power Supply) system will provide power to the entire RMS electrical system, including the CAMAC. The UPS will regulate voltage, frequency, and remove noise from the input line voltage. It will also provide power if the input line voltage is lost. The UPS guarantees a clean and continuous power supply to the RMS and associated equipment. Failure of the UPS system in itself poses no problem because unregulated line voltage will be available.
Loss of input line voltage	Startup, operation and shutdown	Power failure	Loss of electrical power to RMS and hydraulic pump	III	C	4	The UPS system will provide power to the entire RMS electrical system, including the CAMAC. The UPS will provide power for up to 15 minutes if the input line voltage is lost. The UPS guarantees a clean and continuous electrical power supply to the RMS and associated equipment. The pump will lose power, cutting off hydraulic pressure, but the accumulator's discharge will provide a smooth settling
Loss of input line voltage integrity	Startup, operation and shutdown	Noise on the power lines (perhaps due to electrical storm)	Input line voltage is no longer at 115 VAC	III	C	5	The UPS system protects all RMS equipment from voltage surges except the hydraulic system motors. The motors are insensitive to short duration voltage surges.
Failure of electronic signal filters	Operation	Electronic failure in filters	The filtering of the input signal to the servos from the CAMAC is lost	III	C	4	These filters are set at 10 Hz and form the link between the CAMAC system and the electronic conditioning modules. The electronic filters will smooth over any noise in the CAMAC signal. A failure of the filters would cause the data signal to go to 0 volts. This change in voltage would cause the RMS to jump to its neutral position. While this would be unpleasant, it would not cause serious damage. Electronic filters are of a simple design built with highly reliable integrated circuits. The probability of failure is very remote.
Loss of integrity of CAMAC output	Operation	Failure of digital to analog converters in CAMAC	Invalid signals sent to the RMS from CAMAC	II	D	4	The digital to analog (D/A) converters are constructed specifically for industrial use and meet the tough industry standards. In addition, all output data is filtered using the electronic filters which would smooth over any sudden changes in signal. A loss of the D/A converters would probably be detected in the testing phase before the test subject has boarded the simulator.
Poor terrain file	Operation	Mistake in the data file in the computer	Invalid signals sent to the RMS from CAMAC	II	D	4	Data in the CAMAC system to be simulated is generated from well proven analytical models. A limit for vertical acceleration is 6 G's for 40 mSec. All data will be checked against this standard. Additionally, all data is first viewed is a curve on the computer, then plotted on a strip chart recorder and finally used in a test run without the test subject in the RMS.
Loss of position feedback signal on hydraulic actuators	Startup, operation and shutdown	Failure of feedback measurement devices or break in electrical line	Loss of control of hydraulic actuators	II	C	4	Loss of the feedback signal would cause the hydraulic system to operate in an "open loop" mode. In this mode, the actuators will try to track the input signal, but the error in where the actuator should be and where it is will eventually increase so as to force the actuator to a limit. Depending on the input signal, this could happen very quickly or at a slower, less violent pace. Pre-simulation testing and proper maintenance should make it extremely unlikely the feedback signal would be lost during a simulation.

SUBJECT HAZARD OR UNDESIRED EVENT	PROGRAM PHASE	CAUSE	EFFECT	HAZARD SEVERITY	HAZARD PROBABILITY	RAC	COMMENTS CORRECTIVE ACTION/MINIMIZING PROVISIONS
)amage due to :igarette smoking	Operation	Smoke particles damaging the disk drive on the CAMAC system	Loss of ability to read the disk, improper data files read into the CAMAC	III	C	4	Damage to a computer system from smoking is well known and proven. Damage occurs in many forms but the most common is damage done to the disk drive and tape drive by smoke particles, and damage to the keyboard of the terminal. Damage to the tap and disk drives could result in data files being read incorrectly, which may produce violent "glitches" in the simulation. A mandatory ban on smoking in the room prevents this damage.
)il Fire	Startup, operation and shutdown	Ignition of oil from spark or open flame	Possible severe damage depending on the extensiveness of the fire	I	D	5	It is unlikely that the oil could burn since it has a flash point of 395°F. However, pressurized oil from a leak or spray has a greater probability of combustion if it comes into contact with a flame or spark. The main pump motor is of drip-proof construction. Banning any open flames or smoking materials from area will reduce the chance of fire to almost zero.
;tructural 'ailure	Startup, operation and shutdown	Structural fatigue, etc.	Possible severe damage to the RMS depending on the locations and severity of structural damage	II	D	5	A detailed structural analysis was performed by Structural/Kinematics of Troy, MI. The report (listed in the references) stated that there is a less than 10^{-7} probability that the RMS will have a structural fracture occur in the hour of operation following accrued test hours that would result in personal injury to a test subject.
[ncorrect electrical connections	Startup	Improper hookups	Undesirable movement of the simulator. Loss of control	III	C	4	Pre-simulation testing of the seat will reveal any incorrect settings of the control modules or incorrect hookups of the input signal. Corrections will then be made.
Hydraulic Pressure Variations	Startup, operation and shutdown	Variations in supply voltage to hydraulic pump, failure in pump, failure in relief valve	Varying output pressure of hydraulic pump, instead of constant 1500 PSI	III	C	4	Short duration pressure pulses are dampened by the accumulators. Sudden sustained low pressure would indicate a large leak. Sustained high pressure would indicate a relief valve malfunction. A pressure compensated pump is designed to de-stroke in the face of increased pressure, eventually going to near zero. Operator activation of emergency shutdown is the only remedy. A pressure surge does not in itself define an injury situation.
Runaway Vertical Travel	Operation	Incorrect input signal, loss of signal, servo-valve failure, etc.	High acceleration in the up or down vertical travel	II	C	4	The vertical portion of the RMS with an occupant weighs approximately 680 lbs. In the up direction at 1500 PSI operating pressure, there is a possible 4712 lbs of force, limiting maximum acceleration to 4.93 G's (5.93 G's - 1G for gravity). In the downward direction, there is a possible 1749 lbs of force, limiting maximum acceleration to 3.57 G's (2.57 G's + 1 G for gravity). These accelerations are not high enough to cause much damage to the seat or the occupant. The RMS will not hit the travel limits because of travel limiters which eliminate the possibility of sudden impact (with very high G forces).
Aging	Startup, operation and shutdown	Aging of simulator	Wearing and breakdown of almost all equipment on the RMS	II	C	4	The effects of aging show up in all aspects of the simulator. The hoses will deteriorate, electronics may fail, oil will get dirty, moving parts will wear down, etc. The pre-simulation testing and prescribed maintenance schedule will prevent any unforseen complications arising during actual testing.
Vibration of RMS	Operation	Loss of control of RMS.	Vibration possible in all four degrees of motion.	III	C	4	MIL-STD-1472C states acceptable vibration tolerances with time limits of one minut or greater. The operator or occupant has the capability to stop the RMS immediate upon the onset of vibration to the system. Also, the low bandwidths of the RMS wi lower the possibility of any damage occuring.
Operator or occupant errors.	Operation	Inattention, panic or lack of system knowledge.	Failure to stop test, perhaps placing occupant in a dangerous situation.	II	C	4	Failure of either the operator or occupant to stop a test and cause possible damag to the occupant (and equipment) is prevented by providing both people the ability stop a test. If neither person acts to stop a test, additional safety is provided through automatic shutdowns (CAMAC limit control box and servo controller limits) which will automatically stop a test when travel limits have been exceeded.

LIST OF REFERENCES

1) TACOM RDE CENTER Technical Report #13150, "STRUCTURAL ANALYSIS OF TACOM's RIDE SIMULATOR", Charles S. Stanton, April 1986.

2) AR 385-10.

3) MIL-STD-882B.

4) TACOM RDE CENTER Technical Report #13464, "USER's MANUAL FOR THE RIDE MOTION SIMULATOR", Alexander A. Reid, August 1989.

5) TACOM RDE CENTER Technical Report #13470, "SAFETY ASSESSMENT OF TACOM's RIDE MOTION SIMULATOR", Alexander A. Reid, January 1990.

APPENDIX A

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGO.

REFERENCE OR OFFICE SYMBOL	SUBJECT
.iSXP-WAR (385-10i)	Noise and Illumination Survey - Building 215

TO/ THRU C, Safety Ofc (AMSTA-CZ) FROM Industrial Hygienist (HSXP-WAR) DATE 4 Nov 87 CMT 1
Mr. Bonkowski/gpl/4-6256

TO C, Sys Sim & Tech Div (AMSTA-RY)

1. At the request of Mr. Paul Spanski, an Illumination and Noise Survey was conducted in Bldg 215, RMS Bay (Ride Motion Simulator) on 2 Nov 87 by the writer.

2. Test results are on the attached Data Sheet.

3. Findings:
   a. The illumination level at the computer table and control console is below the GSA Illumination Standard of 50 Foot-candles.

   b. Excessive noise levels were not found at this time.

4. Recommendation:
   a. Replacement of the fluorescent lights, and cleaning of the fluorescent light lens.

   b. Request a reevaluation of the illumination levels by the Occupational Health Clinic upon completion of cleaning and repair of lighting fixtures.

K. Bonkowski
KENNETH BONKOWSKI
Industrial Hygienist

Atch

CF:
CPT D. Ellis
(HSXP-SEL)

Bruno Burgess, M.D.
(HSXP-WAR)

ILLUMINATION AND
NOISE DATA SHEET

Building 215, RMS Bay
3 NOV 87

TEST #	LOCATION	ILLUMINATION LEVEL - FOOT-CANDLES
	GSA ILLUMINATION STANDARD	50
1	Computer Table	42
2	Control Console	32 - 39
3	Center of Room	48

TEST #	LOCATION	NOISE LEVEL, dbA
	O.S.H.A. PERMISSIBLE EXPOSURE LIMIT	85
1	At Computer Table	76
2	AT Control Console	80
3	Next_to RMS at floor level	83
4	Door way	75

..CH #1

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGO.

REFERENCE OR OFFICE SYMBOL	SUBJECT
.SXP-WAR (385-10i)	Illumination Re-Survey, Bldg 215

TO THRU C, Safety OFc (AMSTA-CZ) FROM Industrial Hygienist (HSXP-WAR) DATE 1 Apr 88 mr. Bonkowski/gpl/4-6256 CMT 1

TO C, Sys Sim & Tech Div (AMSTA-RYA)

1. At Mr. A. Reed's request, the illumination levels in Bldg 215, Ride Motion Simulator (RMS) room, were re-measured by the writer on 01 Apr 88.

2. The test results are on the enclosed Data Sheet.

3. Findings:
The present illumination levels in the RMS room exceed the value recommended by the Illumination Engineering Society for ordinary seeing tasks (see enclosed Table I, General Recommended Values of Illumination).

4. No further corrective action is recommended.

K. Bonkowski

Encls

KENNETH J. BONKOWSKI
Industrial Hygienist

CF:
CPT D. Ellis
(HSXP-SEL)

Dr. B. Burgess
(HSXP-WAR)

Ms. D. Jones, R.N.
(HSXP-WAR)

Ms. S. Wessel, R.N.
(HSXP-SEL)

ILLUMINATION DATA SHEET
BUILDING 215, RMS ROOM
01 APR 88

TEST #	LOCATION	ILLUMINATION FOOT-CANDLES
	ILLUMINATING ENGINEERING SOCIETY STANDARD FOR ORDINARY SEEING TASKS	30
1	Computer Table	41
2	Control Console	37-39
3	Work Bench	38

ENCL #1

tion will be maintained even where maintenance conditions are favorable, it is necessary to design the system to give initially more light than the recommended in-service level. The system should be designed initially at least 50% above the in-service level. Where safety goggles are worn, the light reaching the eye is likely to be materially reduced, and the level of lighting should, therefore, be increased in accordance with the absorption of the goggle in use. It is important that the quantity of light be measured at the point and in the plane at which the seeing task is performed, be it horizontal, vertical, or some intermediate angle.

(d) The Illuminating Engineering Society has in recent years been studying the illumination needs of specific industries. The results of those studies which have been completed are included in Table II.

2.2.3—*Quality of Lighting*

2.2.3.1—*General*—(a) The factors involved in quality of lighting are many and complex. Glare, diffusion, direction and uniformity of distribution, color, brightness and brightness ratios have a significant effect upon visibility and ability to see easily, accurately, and quickly. Certain seeing tasks require much more careful analysis and higher quality lighting than others. Areas where the seeing tasks are casual or relatively infrequent need high quality lighting much less than areas where the seeing tasks are severe and are performed over long periods of time. Good appearance of certain areas also often dictates the use of high quality lighting even though the seeing tasks in the area are not difficult. Lobbies, auditoriums, etc. usually fall into this class.

(b) Installations extremely deficient in lighting quality are easily recognized as very uncomfortable and even harmful. Unfortunately, more moderate deficiencies are not readily detected, although the cumulative effect of even slightly glaring conditions can result in material loss of seeing efficiency and in undue fatigue.

2.2.3.2—*Direct Glare*—(a) Glare may be defined as any brightness within the field of vision of such character to cause discomfort, annoyance, interference with vision or eye fatigue, or both. When the condition is caused directly by the source of the lighting, whether natural or artificial, it is described as direct glare.

TABLE I.—General Recommended Values of Illumination.

	Current Recommended Practice Footcandles in Service (On Task or 30" above floor)
MOST DIFFICULT SEEING TASKS	
Finest Precision Work	200-1000*
Involving: Finest Detail; Poor Contrasts; Long Periods of Time	
Such as: Extra-fine Assembly; Precision Grading; Extra-fine Finishing	
VERY DIFFICULT SEEING TASKS	
Precision Work	100
Involving: Fine Detail; Fair Contrasts; Long Periods of Time	
Such as: Fine Assembly; High-Speed Work; Fine Finishing	
DIFFICULT AND CRITICAL SEEING TASKS	
Prolonged Work	50
Involving: Fine Detail; Moderate Contrasts; Long Periods of Time	
Such as: Ordinary Bench Work and Assembly; Machine Shop Work; Finishing of Medium-to-Fine Parts; Office Work	
ORDINARY SEEING TASKS	
Involving: Moderately Fine Detail; Normal Contrasts; Intermittent Periods of Time	30
Such as: Automatic Machine Operation; Rough Grinding; Garage Work Areas; Switchboards; Continuous Processes; Conference and File Rooms; Packing and shipping	
CASUAL SEEING TASKS	
Such as: Stairways; Reception Rooms, Washrooms and other Service Areas; Active Storage	10
ROUGH SEEING TASKS	
Such as: Hallways; Corridors; Passageways; Inactive Storage	5

*Obtained with a combination of general lighting plus specialized supplementary lighting. Care should be taken to keep within the general brightness ratios (indicated in Table III) and to avoid glare conditions when light colored materials are involved.

(b) To reduce direct glare, the following steps may be taken:

(1) Decrease the *brightness* of light sources or lighting equipment, or both.

(2) Reduce the *area* of high brightness causing the glare condition.

(3) Increase the *angle* between the glare source and the line of vision.

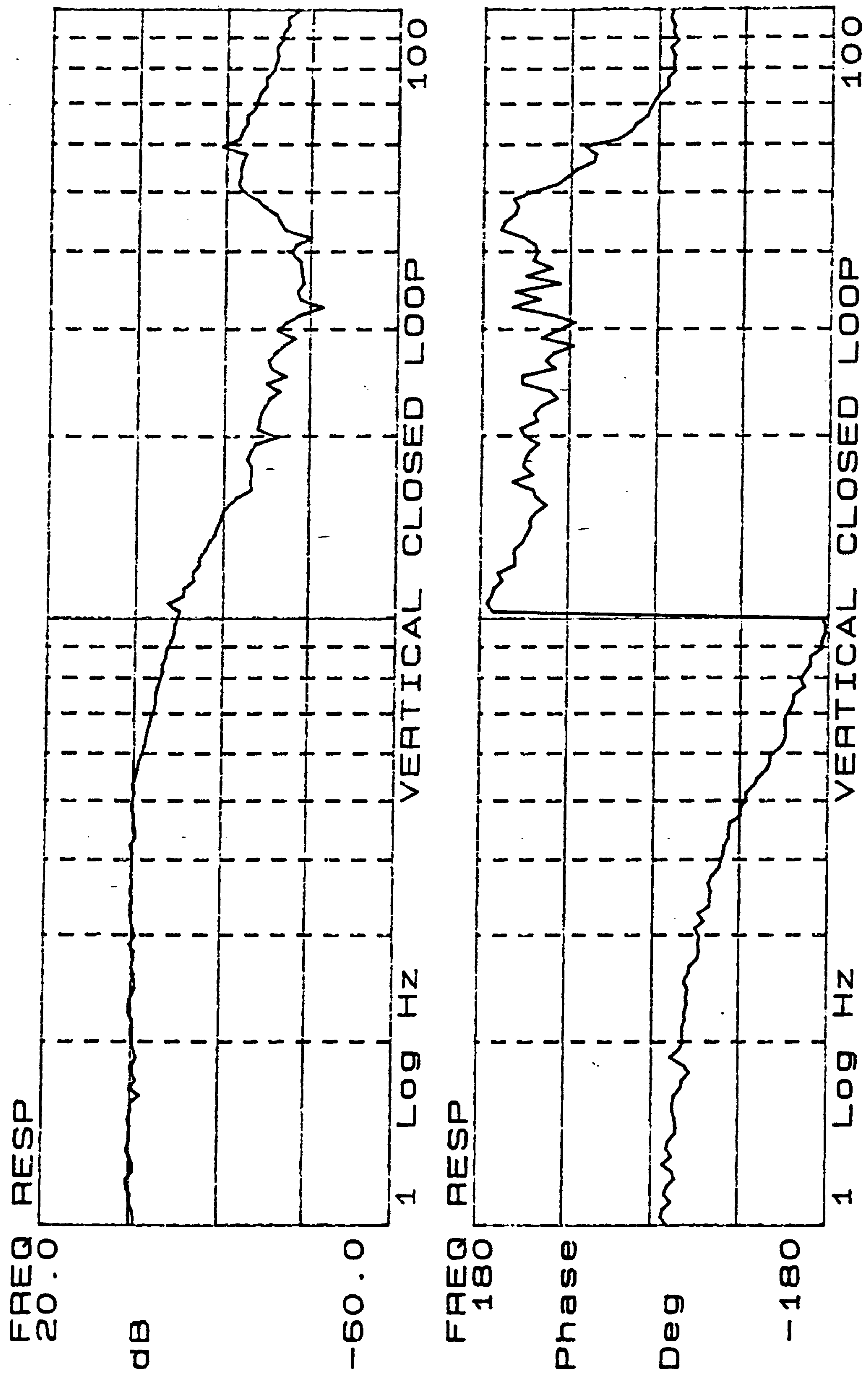
(4) Increase the *brightness* of the area surrounding the glare source and against which it is seen.

(c) Unshaded windows are frequent cause of direct glare. They may permit direct view of the sun, bright portions of the sky, and of bright adjacent buildings. These often constitute large areas of very high brightness in the normal field of view. The condition may be controlled by shading the windows with shades, blinds, louvers, or baffles.

(d) Artificial lighting luminaires which are too bright for the environment in which they are located produce direct glare. To reduce this glare, direct general-lighting luminaires should be mounted at sufficient height to keep them well above the normal line of vision. They should be properly designed to limit both the brightness and the quantity of light emitted in directions directly below the horizontal since such light is likely to be well within the field of view and interfere with vision. There is such a wide divergence of conditions in industry that it is often necessary to modify the ideal luminaire characteristics to meet practical limitations of efficiency and maintenance. In offices and in industrial areas where similar environmental conditions can be established, a shielded zone from horizontal to approximately 45° below is recommended in accordance with the "Recommended Practice of Office Lighting"* (See Fig. 1). It is always desirable to provide as large a shielded zone as practicable. Ideally, from Sec. 2.3.1, the brightnesses of the room should be relatively uniform including the luminaire. This condition is usually difficult to achieve particularly with the direct lighting equipment most frequently used in industry. Usually the surfaces above the lighting equipment and the upper surfaces of

*Published by the Illuminating Engineering Society.

APPENDIX B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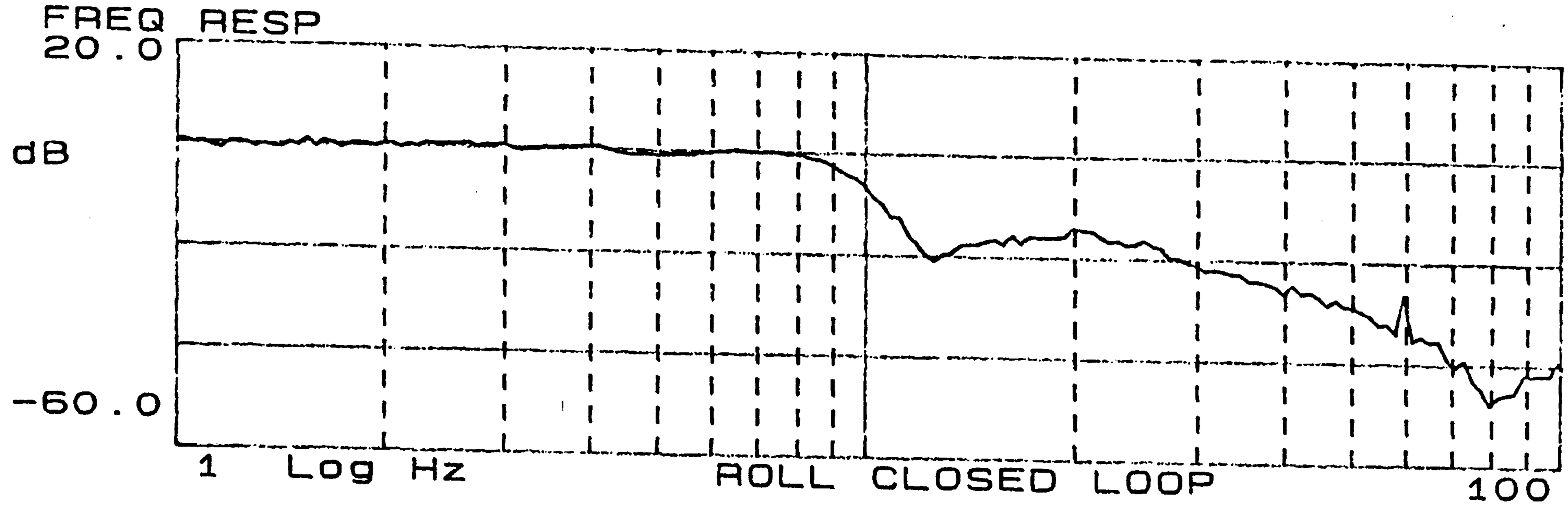
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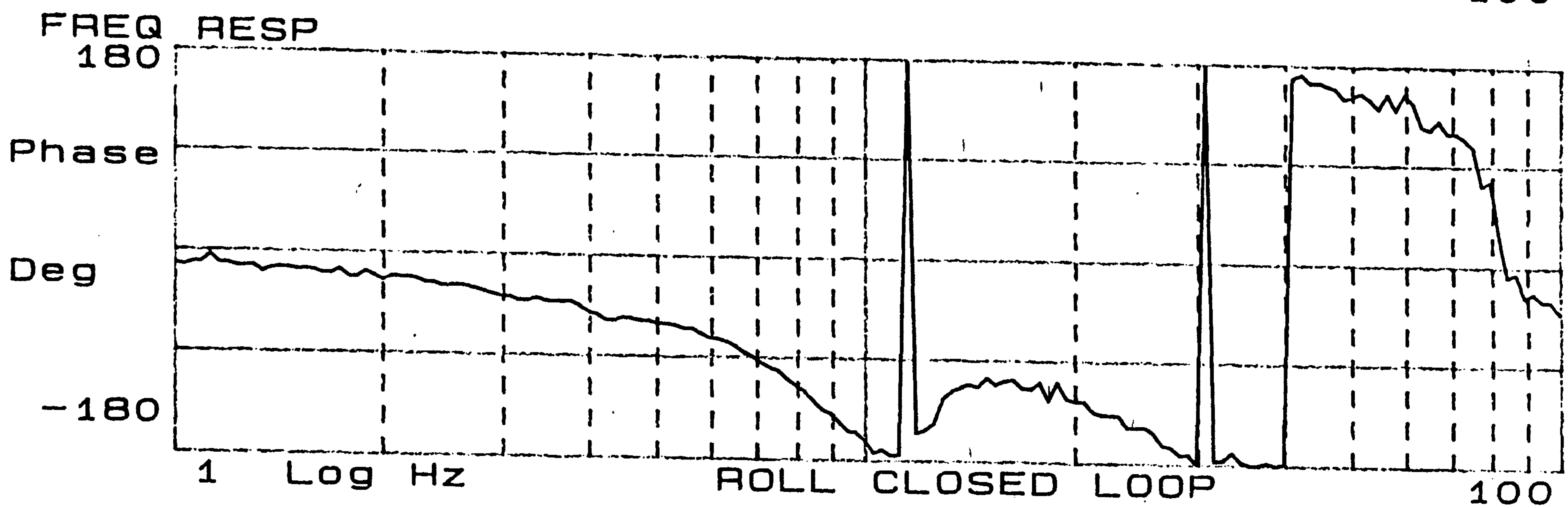
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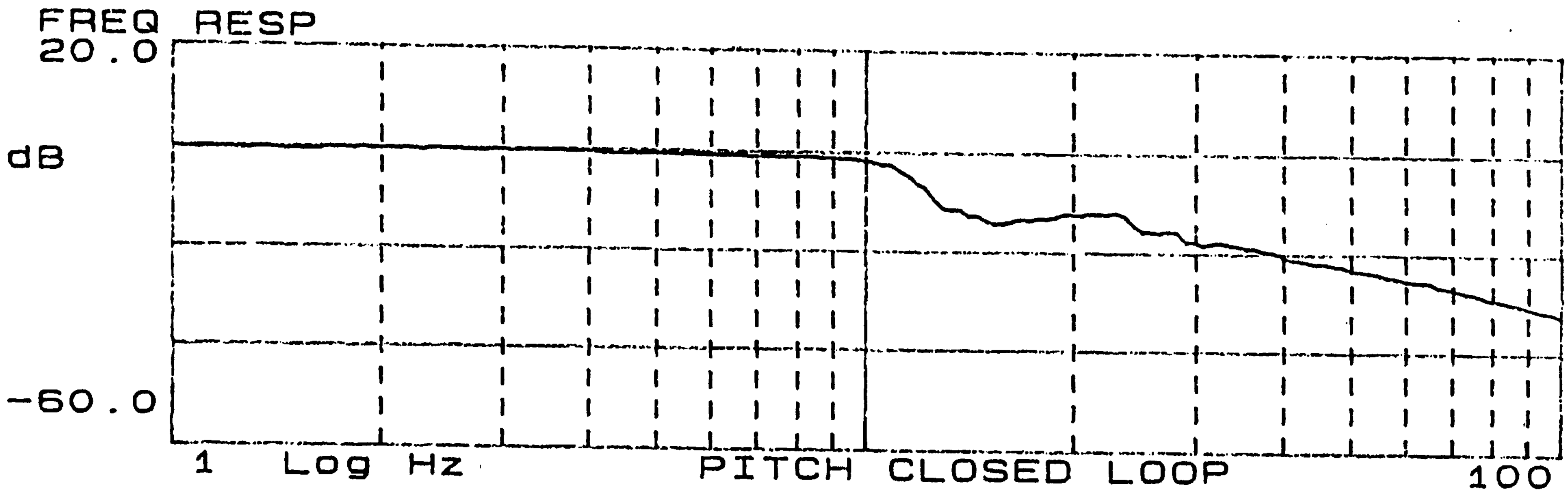
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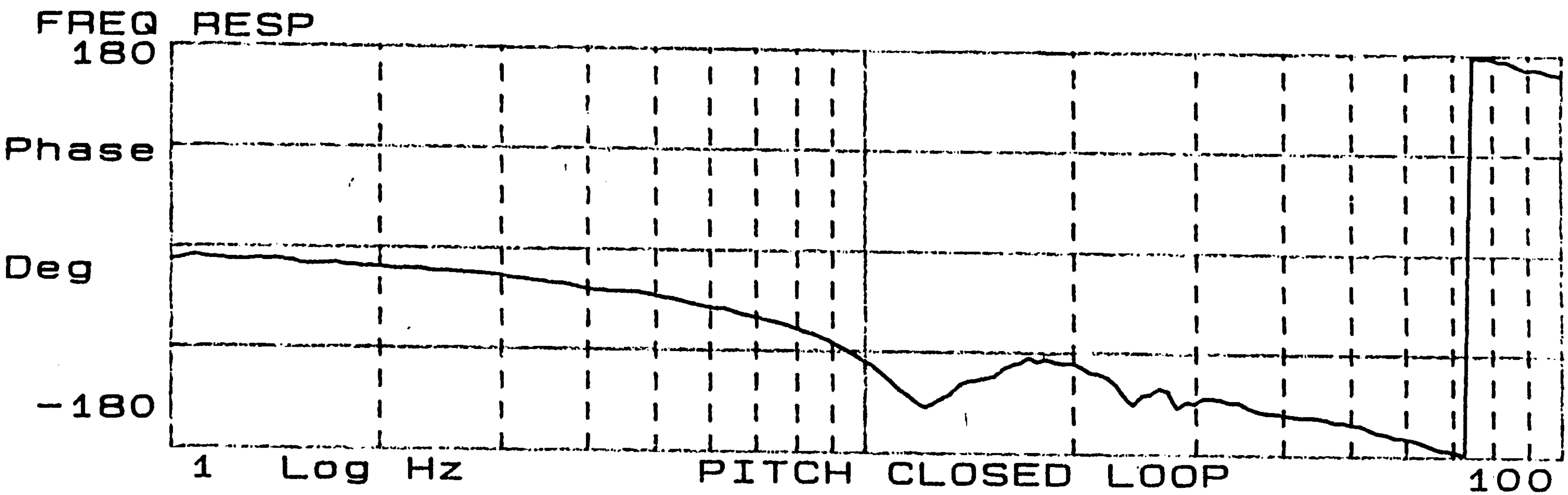
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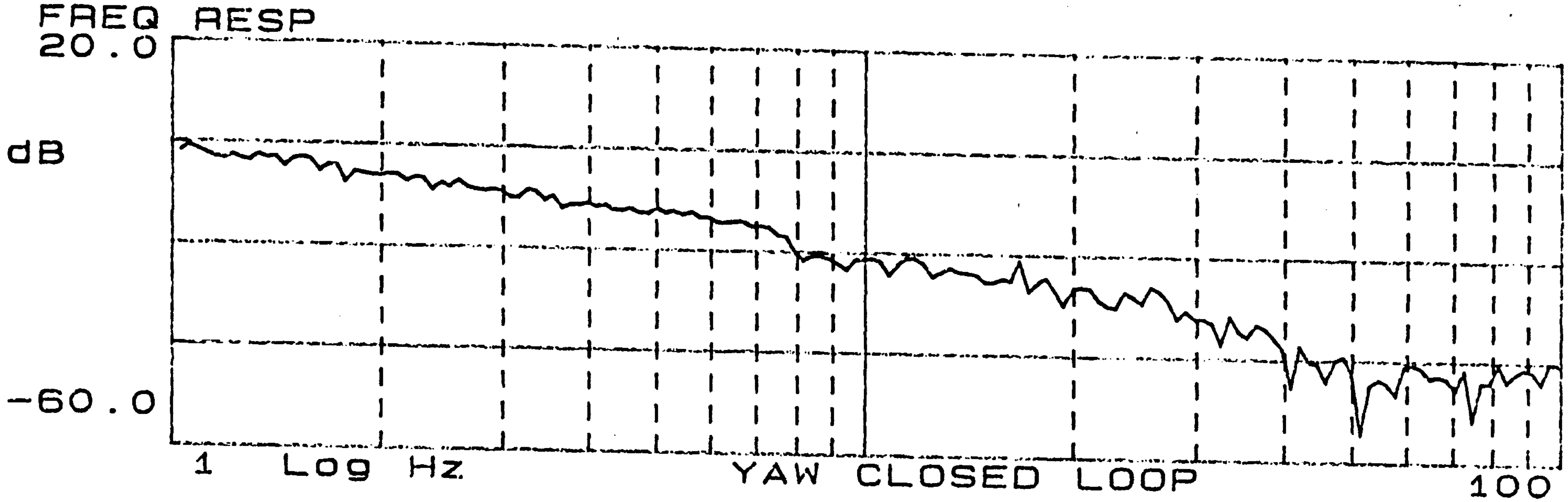
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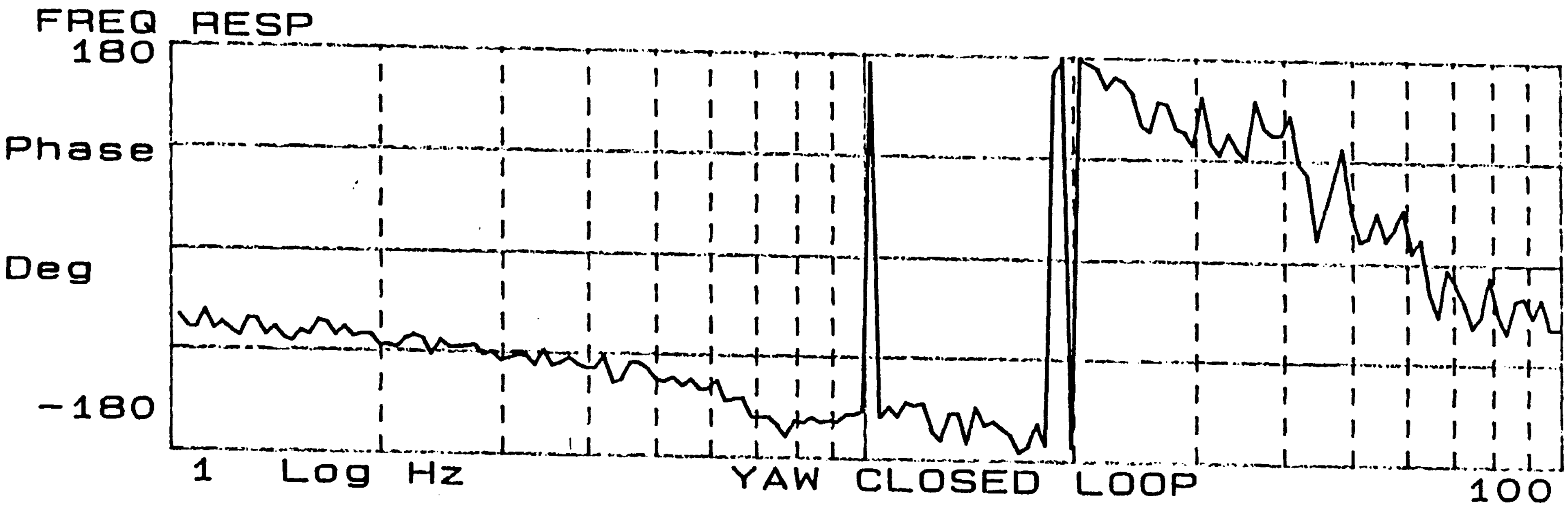
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